

Space Ops 2002
Bringing Space Operations into the 21st Century

Track 3: Operations, Mission Planning and Control

2nd Generation Reusable Launch Vehicle

Concepts for Flight Operations

Jeff Hagopian

Systems Engineering & Integration (UP10)
National Aeronautics and Space Administration (NASA)
Marshall Space Flight Center, Alabama 35812
FAX: +1-256-544-5405, E-mail: Jeff.Hagopian@msfc.nasa.gov

ABSTRACT

With the successful implementation of the International Space Station (ISS), the National Aeronautics and Space Administration (NASA) enters a new era of opportunity for scientific research. The ISS provides a working laboratory in space, with tremendous capabilities for scientific research. Utilization of these capabilities requires a launch system capable of routinely transporting crew and logistics to/from the ISS, as well as supporting ISS assembly and maintenance tasks. The Space Shuttle serves as NASA's launch system for performing these functions. The Space Shuttle also serves as NASA's launch system for supporting other science and servicing missions that require a human presence in space. The Space Shuttle provides proof that reusable launch vehicles are technically and physically implementable. However, a couple of problems faced by NASA are the prohibitive cost of operating and maintaining the Space Shuttle and its relative inability to support high launch rates. The 2nd Generation Reusable Launch Vehicle (2nd Gen RLV) is NASA's solution to this problem. The 2nd Gen RLV will provide a robust launch system with increased safety, improved reliability and performance, and less cost. The improved performance and reduced costs of the 2nd Gen RLV will free up resources currently spent on launch services. These resource savings can then be applied to scientific research, which in turn can be supported by the higher launch rate capability of the 2nd Gen RLV. The result is a win – win situation for science and NASA. While meeting NASA's needs, the 2nd Gen RLV also provides the United States aerospace industry with a commercially viable launch capability. One of the keys to achieving the goals of the 2nd Gen RLV is to develop and implement new technologies and processes in the area of flight operations. NASA's experience in operating the Space Shuttle and the ISS has brought to light several areas where automation can be used to augment or eliminate functions performed by crew and ground controllers. This experience has also identified the need for new approaches to staffing and training for both crew and ground controllers. This paper provides a brief overview of the mission capabilities provided by the 2nd Gen RLV, a description of NASA's approach to developing the 2nd Gen RLV, a discussion of operations concepts, and a list of challenges to implementing those concepts.

1.0 Introduction

The 2nd Generation Reusable Launch Vehicle (2nd Gen RLV) Program is a key component of the National Aeronautics and Space Administration's (NASA's) Integrated Space Transportation Plan (ISTP). The ISTP delineates NASA's strategy for enabling safer, more reliable, and less expensive access to space. The ISTP consists of three major programs:

- 1) Space Shuttle Safety Upgrades,
- 2) 2nd Gen RLV Program, and
- 3) Advanced Space Transportation Program.¹

The focus of this paper is on the 2nd Gen RLV Program, which is envisioned to serve NASA, Department of Defense, and commercial aerospace industry space transportation needs. While there are many areas that contribute towards the cost of space transportation, the emphasis within this paper is on the areas associated with flight operations. The intent of the discussion is to explore a few of the concepts that can significantly contribute towards meeting the cost reduction goals of the 2nd Gen RLV Program. The operations concepts discussed fall into the areas of: 1) Planning, 2) Training, 3) Cadre Certification, 4) Cadre Operations, and 5) Automated Reconfiguration. The concepts identified and discussed in this paper have been derived from experience gained through the operations of past and present space vehicles, with emphasis on the lessons learned from the operations of NASA's Space Shuttle². The concepts discussed here are in no way to be interpreted as requirements on the 2nd Gen RLV Program, but are proposed as areas where additional investigation for applicability may be warranted.

2.0 Terminology

As with most technical areas and programs, there often exists a unique set of terminology. The following are definitions of the key terms used within the context of this paper. These definitions do not constitute the formal definitions of terms used within the 2nd Gen RLV Program, but are intended to be used to help the reader understand the content of this paper. In the event of any conflicts, the definitions contained in 2nd Gen RLV Program documentation have precedence.

Architecture – The integrated set of vehicles, facilities, systems, and people (both flight and ground) required to implement space transportation requirements.

Cadre – A group of trained and certified personnel assigned to perform the ground-based operations functions for flight operations.

Control Center – A ground-based facility used to support or effect the manned and unmanned operations of transportation system vehicles.

Crew – Any personnel aboard an element of the 2nd Gen RLV architecture during launch, ascent, while on-orbit, and/or during descent and landing.

Ground Controller – Ground-based personnel in, or remote from, the Control Center that support or effect transportation system vehicle operations.

Primary Mission – A mission that the 2nd Gen RLV must be capable of performing at Initial Operational Capability, which is currently projected to be the year 2012.

System – A set of interrelated components that interact with one another in an organized fashion towards a common purpose.

3.0 Background

The 2nd Gen RLV Program's long-term goals are to substantially reduce technical and business risks associated with developing safe and reliable RLVs, and to provide affordable and commercially viable space transportation capabilities. The 2nd Gen RLV architecture is currently being defined, with the initial deployment expected early next decade.

NASA's specific overall goals for the 2nd Gen RLV Program are to:

1. Improve safety -- risk to crew, ground personnel, and general population,
2. Improve reliability -- launch availability and success, and
3. Decrease cost -- dollars per pound of payload launched to Low Earth Orbit (LEO).

To accomplish these goals, the 2nd Gen RLV Program will progress through a set of development phases and reviews, as depicted in Figure 3.0-1. This figure depicts the concurrent efforts taking place to define the architecture, while in parallel developing and maturing the technologies required to implement the architecture.

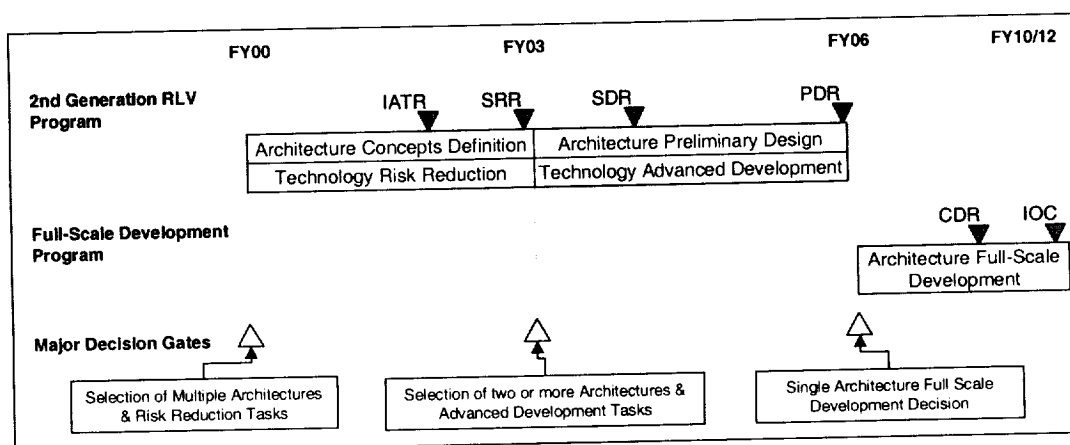


Figure 3.0-1: 2nd Gen RLV Program Development Phases & Reviews

Architecture definition contracts were awarded under NASA Research Announcement (NRA) 8-30 in Fiscal Year 2001. Each of the selected architecture contractors was authorized to define multiple architecture concepts in the process of arriving at a single architecture concept that best satisfies the Program's goals and objectives as defined in the Program Level 1 Requirements document³. The architecture contractors, as a result of significant trades, selected a handful of the most promising concepts in early 2002. These selections were reported to the 2nd Gen RLV Program at the Interim Architecture Reviews (IARs). The Program validated the contractors' rationale for these down-selects using the process defined in the Architecture Convergence Trade Study Plan⁴.

During the Interim Architecture and Technology Review (IATR), the progress and risks associated with technology development activities in support of the 2nd Gen RLV Program were evaluated and reported. These technologies are in development to mitigate current technological shortfalls which preclude the architecture concepts from achieving the Program's goals and objectives. The technology evaluations resulted in improved alignment of technology development with the needs of the architecture concepts remaining in contention.

This iterative process for both the architecture and technology contractors will be repeated throughout the definition and design phases of the Program. The Program will assess the competing architecture designs at the Preliminary Design Review (PDR) in 2006. The PDR will assure that the competing designs meet all system requirements with acceptable risk, and that the correct design options have been selected, interfaces identified and defined, and verification methods satisfactorily planned. As a result of this assessment, the Program plans to select one architecture design to be recommended for full-scale development.

4.0 Missions

The 2nd Gen RLV Program is based on the philosophy that frequently launching NASA payloads on highly reliable, privately-owned-and-operated reusable launch vehicles will significantly reduce the cost of space access, allowing NASA to focus resources on its core missions of scientific discovery and exploration. The primary NASA mission objectives are to provide a launch system and infrastructure capable of:

- Supporting International Space Station (ISS) resupply, maintenance, and crew exchange, and
- Delivering payloads to LEO and other orbit destinations.

It is imperative that the 2nd Gen RLV architecture provides a robust and adaptable space transportation system that not only satisfies the primary mission objectives defined above, but also provides the potential for meeting other mission objectives. These additional missions, while not defined by the 2nd Gen RLV Program as requirements, include missions such as:

- Supporting assembly and checkout of space platforms and modules,
- Servicing and reboosting on-orbit spacecraft, platforms, and other orbital assets,
- Retrieving on-orbit assets for repair and/or service, and return to Earth, if required,
- De-orbiting space debris or inactive spacecraft,
- Delivering payloads to Polar and Sun Synchronous orbits, and
- Performing near Earth exploration crew and vehicle delivery.

It should be noted that the missions listed above are based on NASA mission needs, and are not intended to fully address the mission needs of the DoD and commercial aerospace industry. It should also be stressed that the utility of having an adaptable launch system has been proven by NASA's existing Space Shuttle. While the 2nd Gen RLV is not intended to provide all things to all people, it is important to consider the fact that this new launch system may very well spawn new and innovative uses for which no existing mission needs have been defined.

5.0 Operations Concepts

One of the keys to successful attainment of the 2nd Gen RLV Program goals will be the development and implementation of cost effective operations.⁵ The following sections address just a few of the many areas where operations concepts should be addressed if the cost goals of the 2nd Gen RLV Program are to be realized.

5.1 Planning

For each and every mission, planning is required to produce the products required for both ground and flight operations. The development of these products for NASA's Space Shuttle Program

requires a significant amount of time and manpower. While software tools exist to aid in the development of these products, the existing tools and processes require a significant amount of hands-on interaction. This hands-on interaction often results in planning products that differ in style and content from one mission or revision to next depending on the individual or individuals responsible for their development.

The intent then is to develop and implement planning tools that minimize the human interaction required to build flight planning products. These automated planning tools must provide capabilities for:

- Collecting, interpreting, integrating, and translating scheduling requirements from customers into the format required for use by the scheduling engine.
- Modeling of vehicle capabilities and constraints, and interrelationships between activities to ensure the scheduling engine produces feasible plans.
- Generating initial plans, as well as modifying existing plans to account for changes as a result of ongoing operations and changes in resource availabilities and constraints.

Benefits of implementing automated planning include:

- Shortened planning templates through the elimination of manual data transformation from requirements to software usable models.
- Reduction in modeling errors that result from human interpretation and improper transformation of requirements.
- Improved consistency in planning products as a result of minimizing or eliminating the amount of hands-on interaction required in developing the products.
- Enhanced ability to respond to and incorporate late or changing requirements.

Challenges to implementing automated planning include the following:

- Development and implementation of software tools that collect and translate scheduling requirements.
- Development of requirements collection tools that protect requirements providers from having to know the details of how the scheduling system works.
- Implementation of tools and hardware to support the performance requirements.
- Negotiation and implementation of interfaces with external systems required for mission/flight operations.
- Definition and implementation of scheduling algorithms that result in feasible plans that efficiently utilize critical resources.
- Acceptance of machine generated plans.

5.2 Training

Training for vehicles and mission operations is an area that affects both crew and ground controllers. The current approach to crew and ground controller training focuses on training well in advance of the mission. A variety of training media are utilized, including courses, hands-on, and simulation based training activities. These training activities cover all aspects of operations, including routine operations as well as those operations that potentially affect the safety of the crew and vehicle.

Just-In-Time Training (JIT) is a training methodology whereby the training for an operation is provided just prior to or potentially during the performance of the operation. The implementation of JIT would focus on activities which, while required for successful operations, do not affect the

safety of the crew and vehicle. JIT would be provided through the use of multi-media tools that combine text, audio, and video to provide crew and ground controllers with detailed instructions for performing the required operations. In addition to supporting routine operations, JIT could even be used to support trouble-shooting and repair operations.

Benefits of implementing JIT include:

- Reduces the time required to train crew and ground controllers prior to flight operations, potentially resulting in shortened templates.
- Allows for training to be performed only when required; if a situation or operation is not encountered, then the training does not have to be performed.
- Provides for on-site training to decrease the opportunity for errors and increase the proficiency of the crew and ground controllers; i.e., lessens the reliance on operations from memory.
- Enables revisions to procedures and processes to be effectively communicated to crew and ground controllers.

Challenges to implementing JIT include:

- Design and develop cost effective JIT materials.
- Develop training materials that provide ease of use and navigation.
- Develop hardware and software systems to support crew and ground controller training, including the availability and access to training materials in the operations environment.

5.3 Cadre Certification

The current approach to certification requires ground controllers to be certified for each mission/flight. This certification often requires participation in training activities that are generic or common across missions/flights, and which must be performed or repeated for each mission/flight. This approach to certification requires stringent documentation in support of each mission/flight.

The basic concept is to migrate away from a mission/flight-based certification and implement a skill/qualification-based certification. Periodic recertification would be an integral part of this concept to ensure that required skill levels are maintained. The intent then is to certify crew and ground controllers for certain capabilities independent of a specific mission/flight. Crew and ground controllers would then be assigned to missions and flights based on the capabilities required for the particular mission/flight.

Benefits of implementing cadre certification include:

- Reduces paperwork and record-keeping required in support of each mission/flight.
- Eliminates or minimizes redundant training activities.
- Provides increased flexibility in staffing required functions.

Challenges to implementing cadre certification include:

- Accepting a non-mission/flight based approach to certification.
- Implementing consistent processes, procedures, and products across missions/flights to mitigate the risks associated with mission/flight-independent certified personnel.

5.4 Cadre Operations

Existing approaches to Shuttle and ISS flight operations rely heavily on control center positions, with many positions staffed 24 hours per day, seven days per week (24 x 7).⁶ This approach to

operations requires large numbers of personnel to support the required positions, with many of the functions performed by these positions required only in the event of off-nominal operations.

“Lights Out” control center staffing provides an alternate approach to standard control center staffing. In this approach, control center positions are only staffed for those functions that are required for nominal operations. Every effort is made to minimize the number of positions required for nominal operations, within the constraints of safety and operability. Off nominal operations are supported by on-call personnel. The on-call personnel work remote from the control center environment, both during normal duty hours as well as during off duty hours. In the event of off-nominal operations, the on-call personnel perform required functions through remote access to control center tools and data.

Benefits of implementing Lights Out control center staffing include:

- Reduces overall manpower required to support mission/flight operations.
- Enables personnel to perform other tasks during nominal operations, while maintaining the capability to respond to off nominal operations.
- Provides the ability to apply the best skill mix to the problem or situation encountered.

Challenges to implementing Lights Out control center staffing include:

- Implementing software and hardware systems that provide remote access to control center tools and data.
- Accepting less than immediate response in the event of non-critical off nominal operations.
- Developing information systems to mitigate the lack of situational awareness of on-call personnel.

5.5 Automated Reconfiguration

Throughout ground and flight operations, there are tasks that are routinely performed by the crew and ground controllers. Many of these tasks are performed on a cyclic basis or when particular conditions are encountered. The crew and ground controllers often rely on software systems to inform them when reconfigurations are scheduled or are required to be performed.

The intent of automated reconfigurations is to minimize or eliminate the need for reconfigurations to be performed by the crew and ground controllers. Automating these reconfigurations can be scheduled in advance, or executed based on the occurrence of a pre-defined event or condition. Particular emphasis is placed on automating systems that must be reconfigured on a repetitive and frequent basis.

Benefits of implementing automated reconfigurations include:

- Allows manpower (crew and ground controller) required for reconfigurations to be utilized for other tasks.
- Reduces requirements for procedure development and training.
- Enables reconfigurations to be scheduled and rescheduled without requiring human intervention for scheduling or implementation.
- Eliminates or minimizes the opportunity for error due to differing skill and proficiency levels of crew and ground controllers.

Challenges to implementing reconfigurations include:

- Develop and implement software and hardware systems with capabilities for automated reconfiguration.
- Develop systems to provide crew and ground controllers with appropriate information to assess failures in either the system being reconfigured or the software system performing the reconfiguration.
- Accepting and relying on automated systems for performing reconfigurations.

6.0 Summary

The operations concepts presented in this paper provide just a few of the concepts that can potentially be used to achieve the cost, reliability, and safety goals of the 2nd Gen RLV. Individually, each of these concepts may only provide modest improvements in operations and cost reductions. However, when implemented together or with other operations concepts, the potential for improved operations efficiency and cost reduction can be significant.

The experience gained from previous crewed and uncrewed space operations provides a wealth of knowledge with applicability to 2nd Gen RLV operations. This knowledge, coupled with advances in technologies, provides a great opportunity for the effective and efficient implementation of a new launch system. The challenge then is to enable and encourage new approaches to flight operations.

7.0 References

¹ Space Launch Initiative, *2nd Generation Reusable Launch Vehicle Program Plan*, 2GRLV-PLAN-001; Huntsville, Alabama; National Aeronautics and Space Administration.

² Space Launch Initiative, *2nd Generation RLV Flight Operations Concept Document*, JSC-29590 Draft; Houston, Texas; National Aeronautics and Space Administration.

³ Space Launch Initiative, *2nd Generation Reusable Launch Vehicle Program, Level 1 Requirements*, MSFC-RQMT-3221; Huntsville, Alabama; National Aeronautics and Space Administration.

⁴Space Launch Initiative, *2nd Generation Reusable Launch Vehicle Program, Architecture Convergence Trade Study Plan*, 2GRLV-PLAN-026; Huntsville, Alabama; National Aeronautics and Space Administration.

⁵ Space Launch Initiative, *2nd Generation Reusable Launch Vehicle Program, Operations Concept Document*, 2GRLV-DOC-024 Draft; Huntsville, Alabama; National Aeronautics and Space Administration.

⁶ International Space Station, *Payload Operations Integration Center, Payload Operations Handbook, Volume 2: Increment Operations*, SSP 58312A; Huntsville, Alabama; National Aeronautics and Space Administration.